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PROBLEM OF THE TEMPERATURE DEPENDENCE OF THE BREAKDOWN VOLTAGE IN SILICON p-n JUNCTIONS

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Development of an approximate method for calculating the breakdown voltage for a fast-rise and a linear p-n junction in silicon. A graph showing the calculated and experimental curves expressing the temperature coefficient as a function of the magnitude of the breakdown voltage for the two p-n junctions is presented. Author

The McKay breakdown theory (Bibl.1) is known to lead to the following expression relating the coefficient of collision ionization α with the breakdown width W_B of the p-n junction:

$$\int_0^{W_B} \alpha[E(x)] = 1. \tag{1}$$

The breakdown condition (1) allows the derivation of an expression for the breakdown voltage as a function of the parameters of the p-n transition, if the quantity α is assigned as a function of the field E.

A consideration of collision ionization on the basis of the kinetic /202 equation (Bibl.2) showed that, in the case of a strong field, the dependence of α on the field was given by a complex formula, which could be represented in the form:

$$\alpha = C\Phi[(E/E_1)^{-1/2}, \quad \exp(-E_0^2/E^2)], \tag{2}$$

where C is a constant for a given semiconductor; Φ is a function depending on

* Numbers in the margin indicate pagination in the original foreign text.

the ratio of the field to some characteristic field E_1 in which the mean energy of the carriers becomes of the order of the ionization energy ϵ_1.

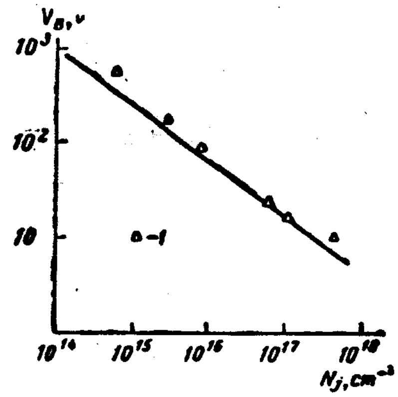

Fig.1 Relation between Breakdown Voltage and Excess Impurity Concentration in the Base for a Sharp p-n Transition
Heavy line: experiment; 1 - Theory

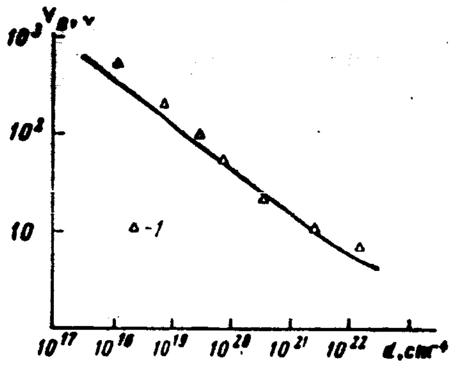

Fig.2 Relation between Breakdown Voltage and Concentration Gradient for a Linear p-n Transition
Heavy line: experiment; 1 - Theory

In this report, we give an approximate calculation of the breakdown voltage for the sharp and linear p-n transitions in silicon. On the basis of experiments (Bibl.3, 4, 5) we selected the ionization energy ϵ_1 = 2 ev and the mean free path for scattering on phonons as $\ell = 10^{-6}$ cm.

Since α depends rigorously on E_1, we found that, for the theoretical and experimental values to coincide, the quantity E_1 must be taken equal to 7 ×

$\times 10^5$ v·cm^{-1}. This is in satisfactory agreement with the theoretical estimate for E_1 in another paper (Bibl.2). Since α is a rigorous function, condition (1)

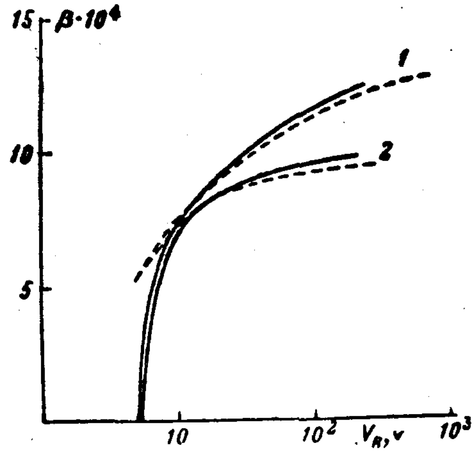

Fig.3 Relation between Relative Temperature Coefficient and the Breakdown Voltage
1 - For abrupt transition (solid curve: experiment; broken line: theory); 2 - For linear transition (solid curve: experiment; broken line: theory)

may be represented in the form

$$\int^{W_B} \alpha[E(x)]dx = m\alpha_{MB}(E_{MB})W_B,$$

where E_{MB} is the maximum field on breakdown, $0 < m < 1$.

It can be shown that the condition (3) leads to a transcendental equation for V_B and for a parameter determined by the structure of the transition. In rough approximation, the solution may be represented:

For an abrupt transition:

$$V_B \neq AN_J^{-\varkappa}, \quad A \simeq 6 \cdot 10^{11}, \quad \varkappa \simeq 0.62, \tag{4}$$

For a linear transition:

$$V_B = Bd^{-\gamma}, \quad B \simeq 6.5 \cdot 10^{10}, \quad \gamma \simeq 0.44, \tag{5}$$

where N_J is the excess impurity density in the base for a steep p-n transition;

d is the concentration gradient for a linear p-n transition.

The relations so obtained are in agreement with experiments (Figs.1, 2). Equations (4) and (5) yield an expression for the relative temperature coefficient of the breakdown voltage. In fact, since $E_1(T) \sim E_{10} \coth^{\frac{1}{2}}(\hbar\omega_0/2kT)$ where ω_0 is the frequency of the optical phonon; h the Planck constant; k the Boltzmann constant; and T the temperature, we have on breakdown:

$$\alpha \simeq \alpha_0(E_{MB}) \exp\left[-\frac{E_{10}^2 \coth(\hbar\omega_0/2kT)}{E_{MB}^2}\right],$$

where α_0 depends weakly on the field.

Making use of eqs.(6) and (3), we obtain after differentiation:

$$\beta = dV_B / dTV_B =$$

for the steep transition,

$$= \frac{E_{10}^2 \mu \hbar\omega_0 V_B^{(1-n)/n}}{\sinh^2 \frac{\hbar\omega_0}{2kT} 8\pi q k T^2 A^{1/n}\left[1 + \frac{E_1^2 \mu}{4\pi A^{1/n}} V_B^{(1-n)/n}\right]}, \qquad (7)$$

or, for the linear transition, /203

$$= \frac{E_{10}^2 (3\mu/\pi q)^{1/3} \hbar\omega_0 3 V_B^{(2-4\gamma)/3\gamma}}{\sinh^2 \frac{\hbar\omega_0}{2kT} kT^2 4.5 B^{1/3\gamma}\left[1 + \frac{16 E_1^2}{9 B^{1/3\gamma}}\left(\frac{3\mu}{\pi q}\right)^{1/3} V_B^{(2-4\gamma)/3\gamma}\right]},$$

where μ is the dielectric constant, and q is the charge of an electron. At T $\simeq$ $\simeq$ 250 - 450°K, eqs.(7) give a weak temperature dependence of β, which practically results in a linear variation of breakdown voltage with temperature. Figure 3 gives plots of the theoretical and experimental dependences for β.

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